EVALUATION OF A STANDING WAVE SYSTEM
FOR DETERMINING THE PRESENCE AND ACOUSTIC
EFFECT OF MICROBUBBLES NEAR THE SEA SURFACE

by

Douglas George Keller

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## ABSTRACT

That bubbles affect sound propagation in the ocean has long been known. However, quantitative data on the concentrations and distribution of bubbles near the surface of the ocean is not available. A one-dimensional, high Q, standing wave system was constructed and evaluated to determine bubble concentrations by measuring the effect of bubbles on the system Q's. It was tested to depths of 40 feet and in the frequency range of 10-100 kHz. This system used a mylar electrostatic transducer as the sound source and also as one of the reflectors. System Q's of 3500 were obtained. It was possible to measure attenuation to ± 0.019 db/m above 20 kHz. Hydrostatic pressure caused variations in the face of the transducer thereby making the system unstable. The mylar transducer is therefore unsuitable for use as both source and reflector. Initial investigations made into using the mylar transducer to externally excite a reflector-reflector system are also described.

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## ACKNOWLEDGEMENTS

The writer wishes to express his appreciation to Professor Herman Medwin of the Physics Department, U.S. Naval Postgraduate School for his guidance and encouragement during the preparation of this thesis; to Mr. William Smith for his assistance in the construction and maintenance of equipment; and to Mrs. Pimporn Zeleny for her work in preparing the programming for computer analysis of data.

## A-1 INTRODUCTION

It is generally known that concentrations of bubbles in the ocean can greatly affect the scattering and absorption of sound. Although bubbles can readily be seen in the ocean in the wakes of ships, in the surf, or in breaking waves, little specific knowledge about the presence and concentrations of bubbles in the open ocean is available. Experiments have been conducted in the laboratory to determine how long bubbles can exist in fresh water.[9] Even though the basic laws of physics indicate that bubbles generated near the surface should rise to the surface and dissipate in a short time, the results of these experiments indicate that bubbles of radii less than 30 microns may actually stabilize and remain suspended indefinitely. Bubbles of larger radii have been found to persist as long as 100 hours.

This project was undertaken to design and test a system which could be used to make "in situ" measurements of the effect of bubble concentrations in the ocean to depths of about 40 feet. The frequency range of interest was set at from 10 kHz to 100 kHz. Previous investigations in this area, although capable of providing some data, were limited by slow and laborious data taking and evaluation processes.[1,2] The object of this project was not only to produce a system which would provide data, but provide it quickly and with maximum possible ease of evaluation.

To achieve these goals a one-dimensional, standing wave, high Q system which could be automatically swept through a series of resonant peaks was designed and evaluated.

## A-2 THEORY

The quality factor, Q, of a resonant system may be described (5) by the relation

$$Q = f_o/BW \qquad \text{(I)}$$

where $f_o$ is a resonant frequency

BW is the half power bandwidth

or as

$$Q = \pi/\alpha\lambda \qquad \text{(II)}$$

where $\alpha$ is a spatial attenuation constant in nepers/meter

$\lambda$ is the wavelength in meters.

The effect of bubbles on the attenuation of acoustic waves may be experimentally determined in the following manner:

1) The system is first made to resonate in bubble free water and the Q value ($Q_1$) determined from equation (I).
2) Using this value of $Q_1$ in equation (II), a value of $\alpha(\alpha_1)$ may be obtained as

   $$\alpha_1 = \pi/Q_1\lambda$$
3) Repeat this procedure in water containing bubbles and compute a new value of $\alpha(\alpha_2)$.
4) Let $\alpha = \alpha_2 - \alpha_1$ and $\alpha =$ the increase in attenuation in nepers/meter due to bubbles.
5) Now $\alpha = \frac{\pi}{\lambda}\left(\frac{1}{Q_2} - \frac{1}{Q_1}\right)$ nepers/meter

or $\alpha = \frac{\pi}{c}(BW_2 - BW_1)$ nepers/meter.

This may be converted to

$$a = \frac{8.68\pi}{c}(BW_2 - BW_1) \text{ db/meter} \qquad \text{(III)}$$

where c is the speed of sound in meters/sec.[6]

The value of $a$ in db/meter at a given frequency can now be used to obtain an approximation of the number of bubbles in the water which are resonant at that frequency. Two assumptions must be made. First, it is assumed that any absorption is due to bubbles rather than to solid matter. This is a valid assumption since the effective cross section of a resonant bubble is many times larger than the geometric cross section.[2] The second assumption is that at the resonant frequency, the attenuation is due primarily to bubbles which are resonant at that frequency. (If a constant and continuous distribution of bubbles is assumed and a tone is generated in the water, approximately 71% of the resulting attenuation is due to those bubbles within 10% of the resonant size.[7])

If these assumptions are made it can be shown from classical theory[8] that

$$a = 2\pi^2 R_r N / \delta_r \qquad \text{(IV)}$$

where $R_r$ is the resonant bubble radius

$N$ is the number of resonant bubbles per unit volume

$\delta_r$ is the resonant bubble damping constant.

Approximate values for $R_r$ and $\delta_r$ may be obtained using the relations[9]

$$R_r = \frac{1}{2\pi f}\sqrt{\frac{3\gamma P_0}{\rho}}\sqrt{\frac{g}{\tau}} \tag{V}$$

$$\delta_r = \frac{1}{c}\sqrt{\frac{3\gamma P_0}{\rho}}\sqrt{\frac{g}{\tau}} \tag{VI}$$

where f = frequency of acoustic energy

c = speed of sound in the medium

$\gamma$ = ratio of specific heats for the gas enclosed in the bubbles

P = ambient pressure

$\rho$ = density of the fluid medium

g = a correction factor to correct for the influence of surface tension. Its value is 1 for bubbles of radii greater than 10 microns and increases for smaller radii

$\tau$ = a correction factor for $\gamma$. $\gamma$ approaches 1.40 for large bubbles and 1.00 for small bubbles.

Putting (V) and (VI) into (IV) and solving for N (with $\gamma = 1.40$ for air and $\rho = 10^3$ Kg/m$^3$ for water) gives

$$N = \frac{683 f^3 a \tau}{P_0 c g} \tag{VII}$$

with f in Sec$^{-1}$

a in meters$^{-1}$

$P_o$ in Newtons/meter$^2$

c in meters/sec.

## B-1 GENERAL SYSTEM DESCRIPTION

This project was undertaken to determine a method by which the bubble concentrations in the upper 40 feet of the ocean could be measured in the frequency range from 10 kHz to 100 kHz. Qualities desirable in a system to be used for this purpose would be:

1) Ease in handling for at sea measurements.
2) Ability to accurately obtain a large number of data points in the frequency range of interest as quickly as possible.
3) Ease in compiling and analyzing data obtained.

To obtain these qualities a transducer-reflector, standing wave system, resonant at many points in the region of interest, was investigated. (Figure 1) The frame was made of $2\frac{1}{2}''$ thin walled stainless steel tubing to provide maximum strength with minimum weight and negligible sea water corrosion. The transducer was a 24" diameter mylar electrostatic transducer (Figure 2). A transducer of this size is not only highly directive (directivity index, $d \approx 76$ db at 50 kHz), minimizing divergence losses, but also is large enough to act as one of the reflectors of the system. The other reflector was 40" square and composed of a $\frac{1}{4}''$ aluminum plate covered with a $\frac{1}{4}''$ thickness of polyethylene foam which acted as a pressure release surface. The polyethylene was then covered with 2 coats of liquid neoprene to keep

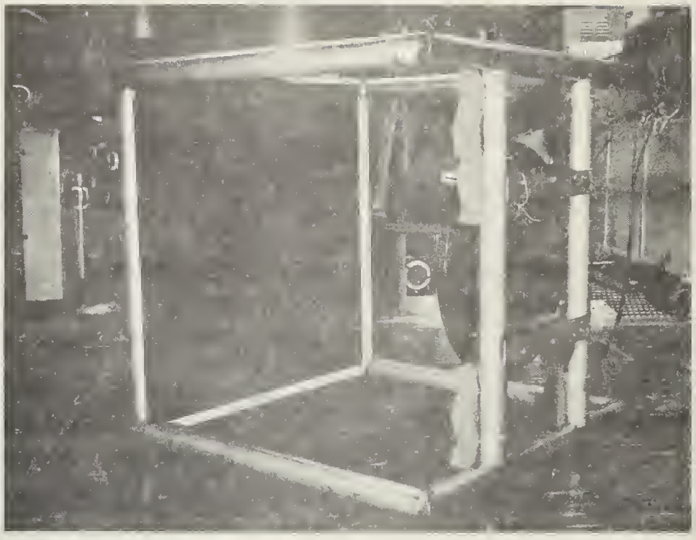


FIGURE 1 24" MYLAR TRANSDUCER AND 40" ALUMINUM - POLYETHYLENE REFLECTOR MOUNTED IN $2\frac{1}{2}$" STAINLESS STEEL FRAME.

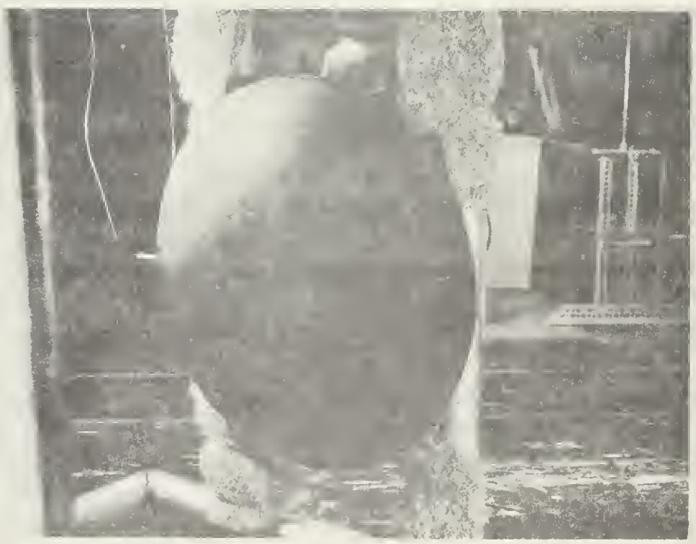


FIGURE 2 24" MYLAR TRANSDUCER MOUNTED IN THE STAINLESS STEEL FRAME.

water from penetrating the surface and changing the reflecting characteristics of the polyethylene. A 1/8" diameter, ½" long, barium titanate hydrophone was inserted from the rear of the reflector approximately ½" into the acoustic pattern. Transducer-reflector separation varied from 77 cm. to 83 cm. depending on the transducer used (several models were used during the course of experimentation). The transducer and reflector were made parallel using a meter stick. Using this method it was possible to get them parallel to within 1 mm. With the transducer-reflector spacings used, the system was acoustically resonant every 900 Hz to 1 kHz yielding approximately 90-100 resonance peaks in the frequency range of interest (10 kHz-100 kHz).

A frequency response curve was obtained by using an oscillator which linearly swept the frequency range of interest and by recording the system frequency response. The electronic components of the system are shown in Figure 3 and equipment designations given in Table I. For this system investigation the frequency response was recorded using a voltage level recorder and the response analyzed by hand. However, the frequency response could be tape recorded and the recording analyzed by computer for increased accuracy and ease of analysis. The programming for such digital analysis has been initiated and is now close to completion.

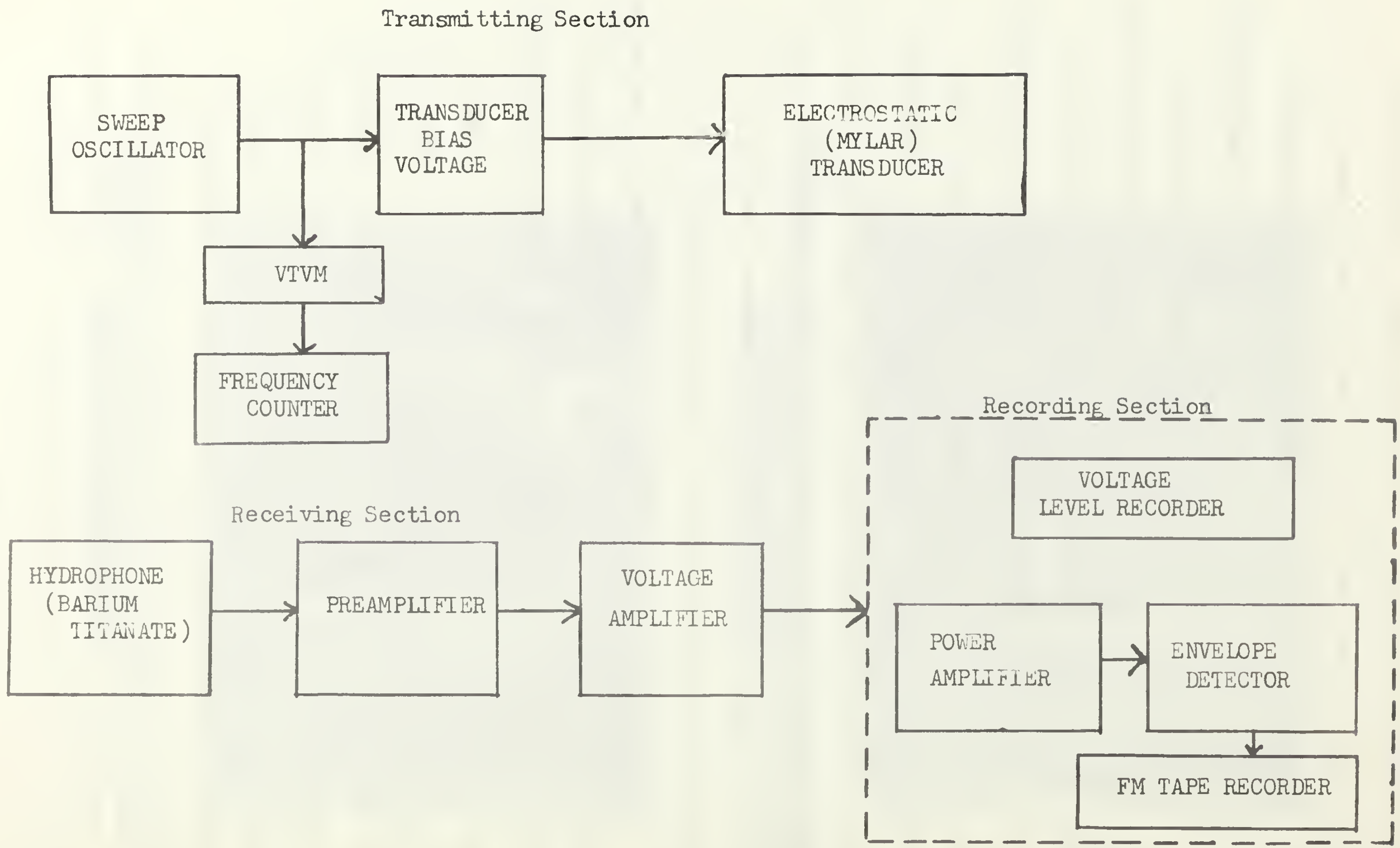



FIGURE 3 SYSTEM COMPONENTS

TABLE I

SYSTEM ELECTRONICS

(Corresponding to Figure 3)

| As Designated in Figure 3 | Equipment Designation |
|---|---|
| Sweep Oscillator | WAVETEK 114 Oscillator |
| VTVM | HP 400A VTVM |
| Frequency Counter | HP 5232A Electronic Counter |
| Transducer Bias Voltage | 300 v. Battery |
| Electrostatic Transducer | See Figure 9 |
| Hydrophone | See Section B-4 |
| Preamplifier | See Figure 5 |
| Voltage Amplifier | Scott Decade Amplifier Type 140A |
| Voltage Level Recorder | B & K Type 2305 Voltage Level Recorder |
| Power Amplifier | HP 467A Power Amplifier |
| Envelope Detector | See Figure 8 |
| FM Tape Recorder | Precision Instrument 6200 Tape Recorder |

## B-2 OSCILLATOR

The oscillator used was a WAVETEK 114 with a linear time sweep. Since, if the sweep speed is too great, the resonance pattern will not develop fully, tests were made to determine the maximum permissible sweep speed to produce accurate system response curves. Sweeps were made at various sweep rates (from 13 Hz/sec to 350 Hz/sec) over resonance peaks at 18 kHz, 33 kHz, 45 kHz, 66 kHz, and 85 kHz. Using the slowest sweep speed as a base, it was possible to plot increase in bandwidth vs. sweep speed as a function of frequency to determine the maximum permissible sweep speed. These results are shown in Figure 4. It can be seen that above a sweep rate of about 100 Hz/sec the bandwidths of the resonance peaks increases. For this reason runs were limited to sweep rates of less than 100 Hz/sec. Since the maximum time this oscillator will sweep is about five minutes, it was necessary to use at least three runs to cover the frequency range of interest (10 kHz to 100 kHz).

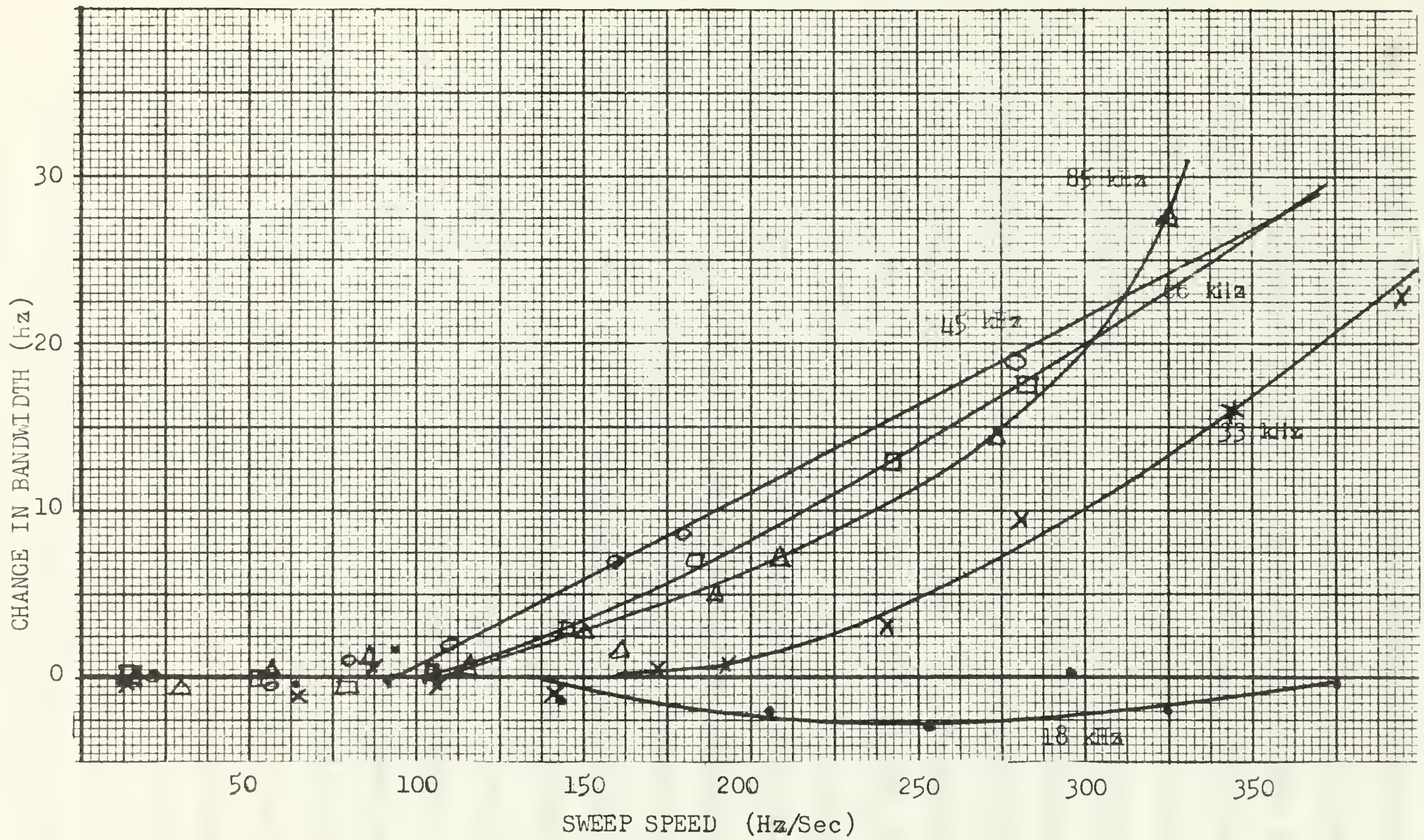



FIGURE 4 CHANGE IN BANDWIDTH (Hz) VS SWEEP SPEED (Hz/Sec)
FOR FIVE SELECTED RESONANCE PEAKS

## B-3 RECORDING SECTION

During the evaluation of the resonant system, a B & K Model 2305 Voltage Level Recorder was used to directly record the system frequency response. The sweep starting and ending frequencies and the time of the run were recorded. The sweep rate was assumed constant and the paper tape could then be calibrated in terms of frequency and analyzed.

By analyzing consecutive runs it was determined that resonance peak widths of approximately 25-70 Hz could be obtained with accuracies of ±2 Hz below 20 kHz and ±1 Hz above 20 kHz. This is equivalent to ±0.037 db/meter below 20 kHz and ±0.019 db/meter above 20 kHz. Two sea trials were conducted in relatively calm seas on cloudy days. Although such conditions are minimal for the production of bubbles, it is clear that under these conditions the effects of bubble concentrations were too small to be effectively determined with the current degree of system accuracy.

The major source of error is the ability to read bandwidths from the paper tape. This can be accomplished with an accuracy of approximately ±1Hz. This error can be reduced or eliminated by using the following recording and analyzing method: Envelope detect the frequency response signal; then F-M record the varying DC response envelope on magnetic tape. (Direct recording would require a high tape speed and the signal would not be

suitable for low sample rate digitation and computer analysis.); finally digitize the recorded signal and analyze using a computer. Using this method the human limitations of analysis are removed. Errors in determining the resonant frequency and the half power points can be made as small as desired by increasing the digitizing sampling rate.

If this method does not produce accurate, repeatable results and it is felt that the oscillator sweep speed is varying during the run, the sweep control voltage could be recorded on another channel of the magnetic tape simultaneously with the system response signal. By recording the sweep control voltage for known reference frequencies (such as the run start and stop frequencies) at the beginning of each run and assuming linearity between control voltage and oscillator frequency, the frequency at any point on the system response may be determined from the magnitude of the corresponding control voltage sample. This method would detect and correct for any variations in the oscillator sweep speed.

It must be remembered that the limiting factor on system accuracy is the stability of the system in reproducing the frequency response from run to run. The difficulties of obtaining reproducibility with this system is considered in section B-8.

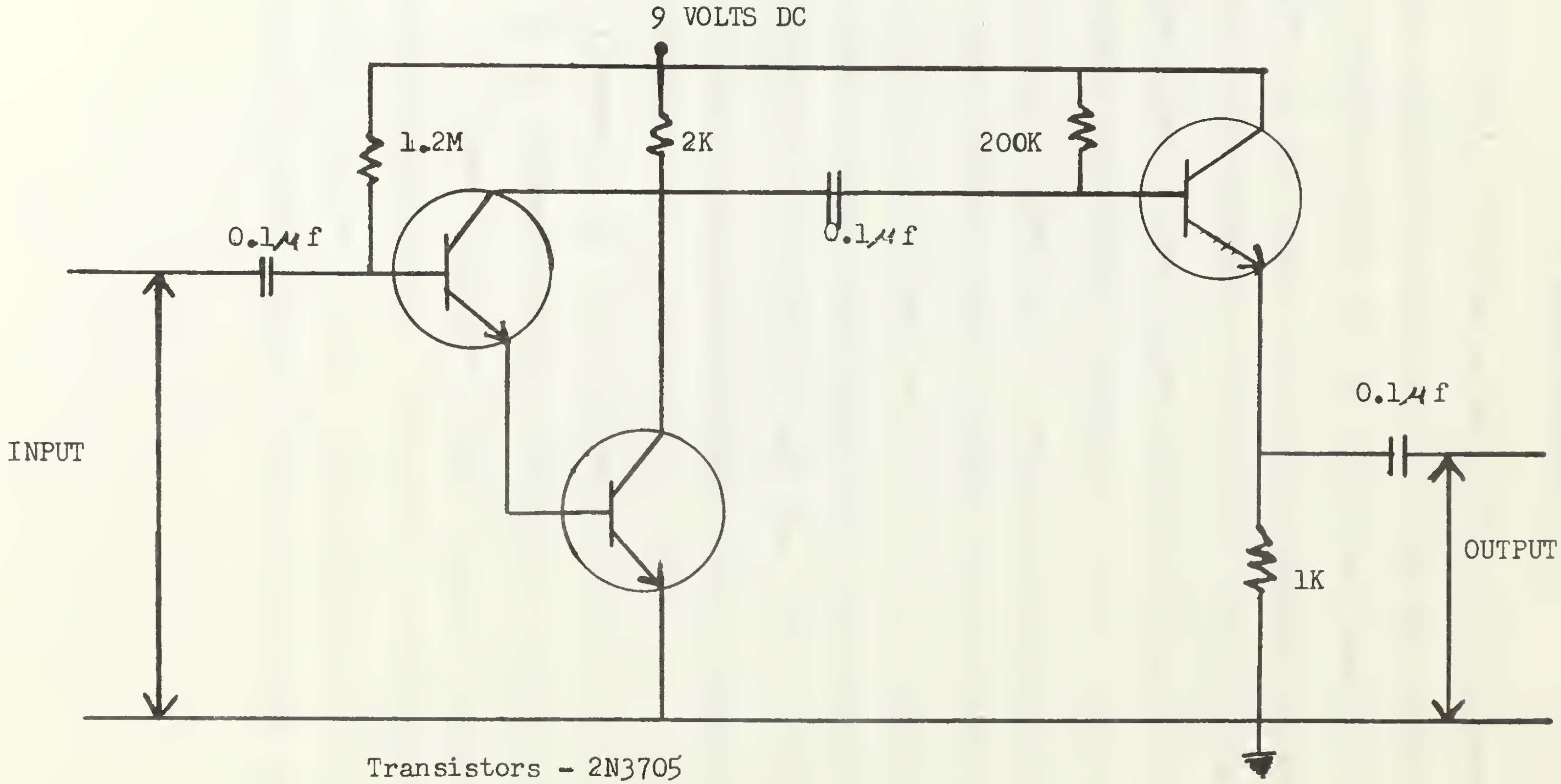
## B-4 HYDROPHONE

The hydrophone used was 1/2" of a 1/8" barium titanate ceramic cylinder. This hydrophone was small enough not to excessively disturb the standing wave pattern, yet sensitive enough to pick up the pressure levels involved. It was inserted through the back of the reflector about 1/2" into the center of the major lobe of the transducer pattern.

An attempt was made to mount a 1" barium titanate disc in the reflector, both flush with the reflector and at varying distances into the pattern. This hydrophone was too large and disturbed the pattern at frequencies above 50 kHz. Also since the reflector was acting as a pressure release surface the response was poor.

## B-5 PREAMPLIFIER

When the hydrophone was attached to 150 feet of coaxial cable (RG 59A/U), the noise level was high enough to obscure portions of the system response. Also, any disturbance along the length of the cable caused large noise spikes which overrode the response signal. To provide signal amplification and impedance matching near the hydrophone a preamplifier (Figure 5) was designed and installed. The preamplifier was encased in a block of plastic resin (FITZ E Clear Casting Resin), placed in an aluminum container with an external battery connection which had been insulated with liquid rubber (Figure 6), and the container was sealed with liquid neoprene. The preamplifier was installed in the cable, two feet from the hydrophone, and clamped to the back of the reflector (Figure 7). This preamplifier provided signal enhancement (approximately 40 db to an open circuit) and the noise reduction required. With the preamplifier in operation the hydrophone was no longer sensitive to external cable motion and the noise level was more than 15 db below the peak signal levels.




Transistors - 2N3705

FIGURE 5 PREAMPLIFIER CIRCUIT DIAGRAM

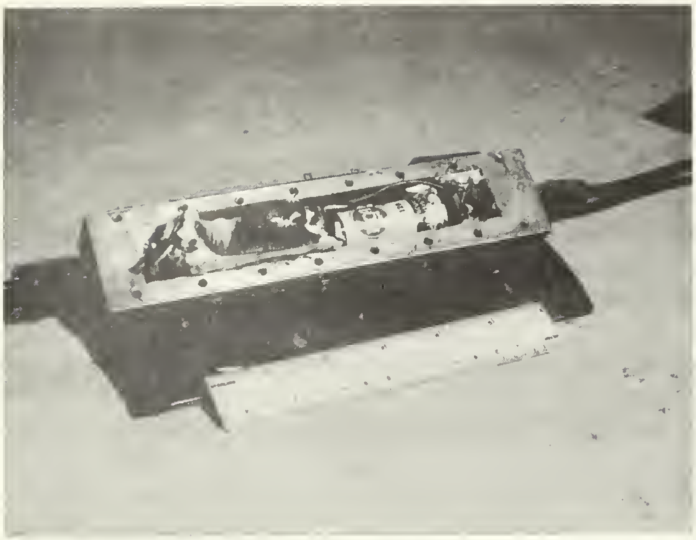


FIGURE 6 PREAMPLIFIER ENCASED IN PLASTIC RESIN AND INSERTED IN ALUMINUM CONTAINER.

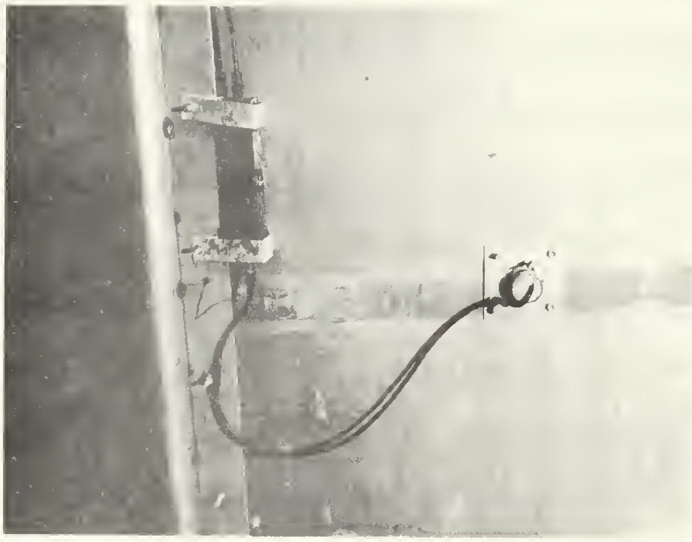


FIGURE 7 PREAMPLIFIER CLAMPED IN POSITION ON BACK OF REFLECTOR.

## B-6 ENVELOPE DETECTOR

A simple R-C envelope detector (Figure 8) provided linearity for an input greater than 0.5 volts rms with a maximum a.c. ripple of 0.94% at 10 kHz. This detector would be used when using the tape recorder. The a.c. ripple would be completely removed by the inability of the tape recorder to record frequencies above 1 kHz at 3.75 ips.

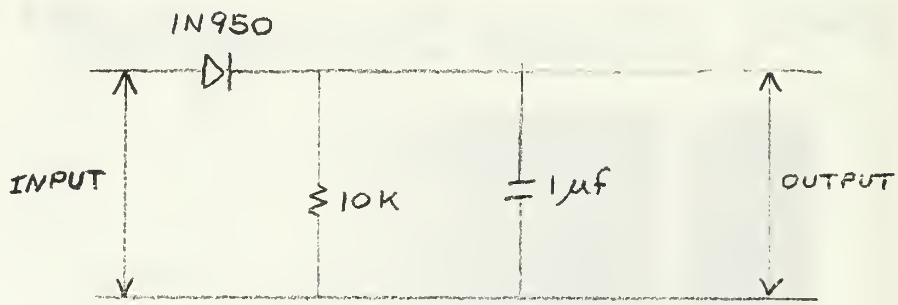



FIGURE 8 ENVELOPE DETECTOR CIRCUIT

## B-7 REFLECTOR

In designing the system it was necessary to keep in mind that this unit was being developed to operate at sea. For this reason the requirement for the reflector material was not only maximum reflection throughout the frequency range of interest, but also minimum weight. Therefore, steel was not considered as a reflector material even though it would have provided better reflecting properties than aluminum (which was tested).

Three reflecting materials were investigated during preliminary project work on a resonant standing wave system.[4] These reflectors were a $\frac{1}{4}$" aluminum plate, the $\frac{1}{2}$" aluminum plate covered with a $\frac{1}{2}$" layer of polyethylene foam, and the aluminum-foam combination covered with a 1 mil layer of mylar (to act as a waterproofing for the foam and to prevent air bubbles from forming on the surface of the foam). Subsequently tried were 3/4" plywood treated with liquid plastic as a waterproofing, and the plywood covered with the $\frac{1}{2}$" polyethylene foam.

The criterion used for selection of the material to be used was to determine the Q's obtained using the various reflector materials over the range of interest. The best results were obtained using the combination aluminum and polyethylene reflector. Comparable results were obtained above 60 kHz with both the plain aluminum and the wood backed polyethelene reflectors, but enhancement at lower and middle frequencies was provided by

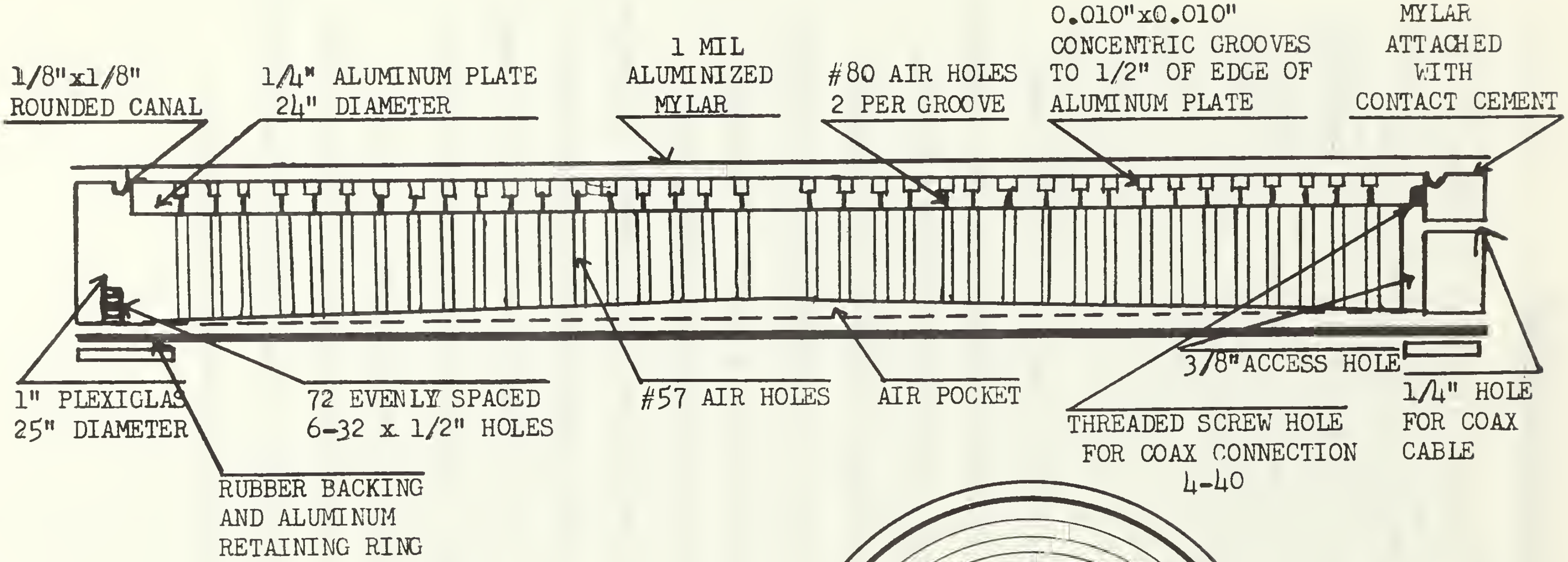
using the combination aluminum-polyethelene reflector. Liquid neoprene was used to seal the polyethelene because the mylar coating was difficult to apply and air bubbles tended to form between the mylar and the foam. Although the use of a double reflector introduced additional interference effects into the frequency response pattern of the system, this disadvantage was more than offset by the increased Q values at the low and middle frequencies.

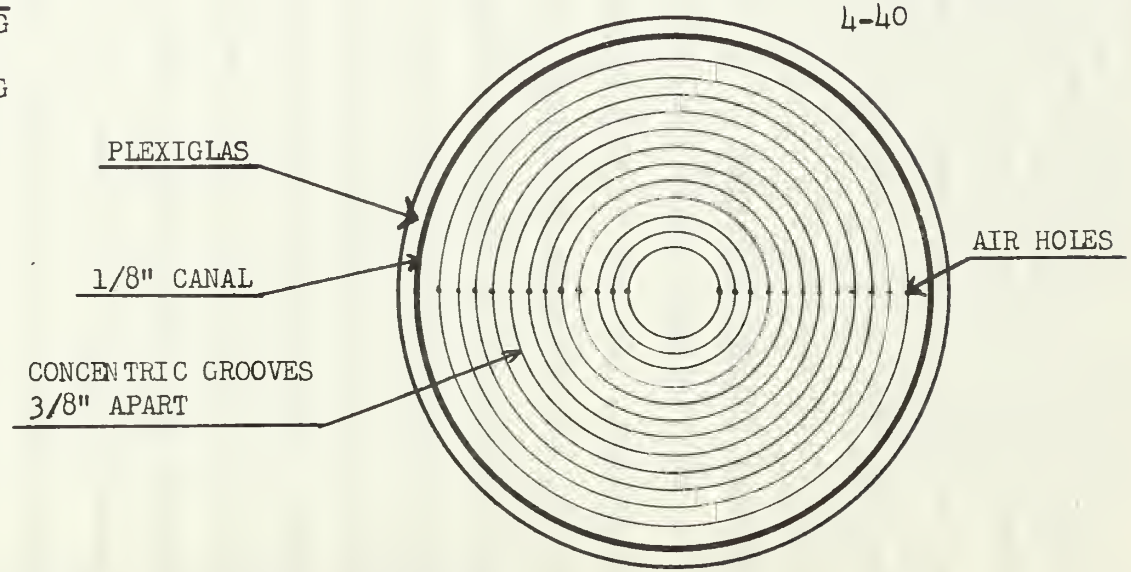
## B-8 MYLAR TRANSDUCER

The basic design of the 24" diameter electrostatic mylar transducer used is shown in Figure 9. Polarizing voltage used was 300 volts d.c. The applied alternating voltage was limited to less than 7 volts rms, as voltages in excess of this value caused distortion in the output.

### General Design Problems

Preliminary tests indicated that this design was unsuitable for use in the resonant system for two reasons. First, the frequency response pattern developed by the system was not a simple resonance pattern, but showed many interference effects such as; unsymmetric resonance peaks, multiple peaking points near a given resonance, small, low Q peaks between expected resonances, and 10-15 db variations in the amplitude of adjacent minimums. (Figure 10) The second effect was that the difference in external pressure between the top and bottom of the transducer when it was submerged forced the air to the top of the transducer and stretched the mylar face, thereby changing the transducer's reflecting characteristics and the resulting resonance patterns. The smallest bandwidths obtained with this transducer were about 90-100 Hz at 75-85 kHz ($Q \approx 800$).




NOTES:

1) ALUMINUM PLATE HELD TO PLEXIGLAS BY FOUR SCREWS
2) ALUMINUM PLATE PROTRUDES ABOUT 0.005" ABOVE PLEXIGLAS BASE

FIGURE 9 24" MYLAR TRANSDUCER

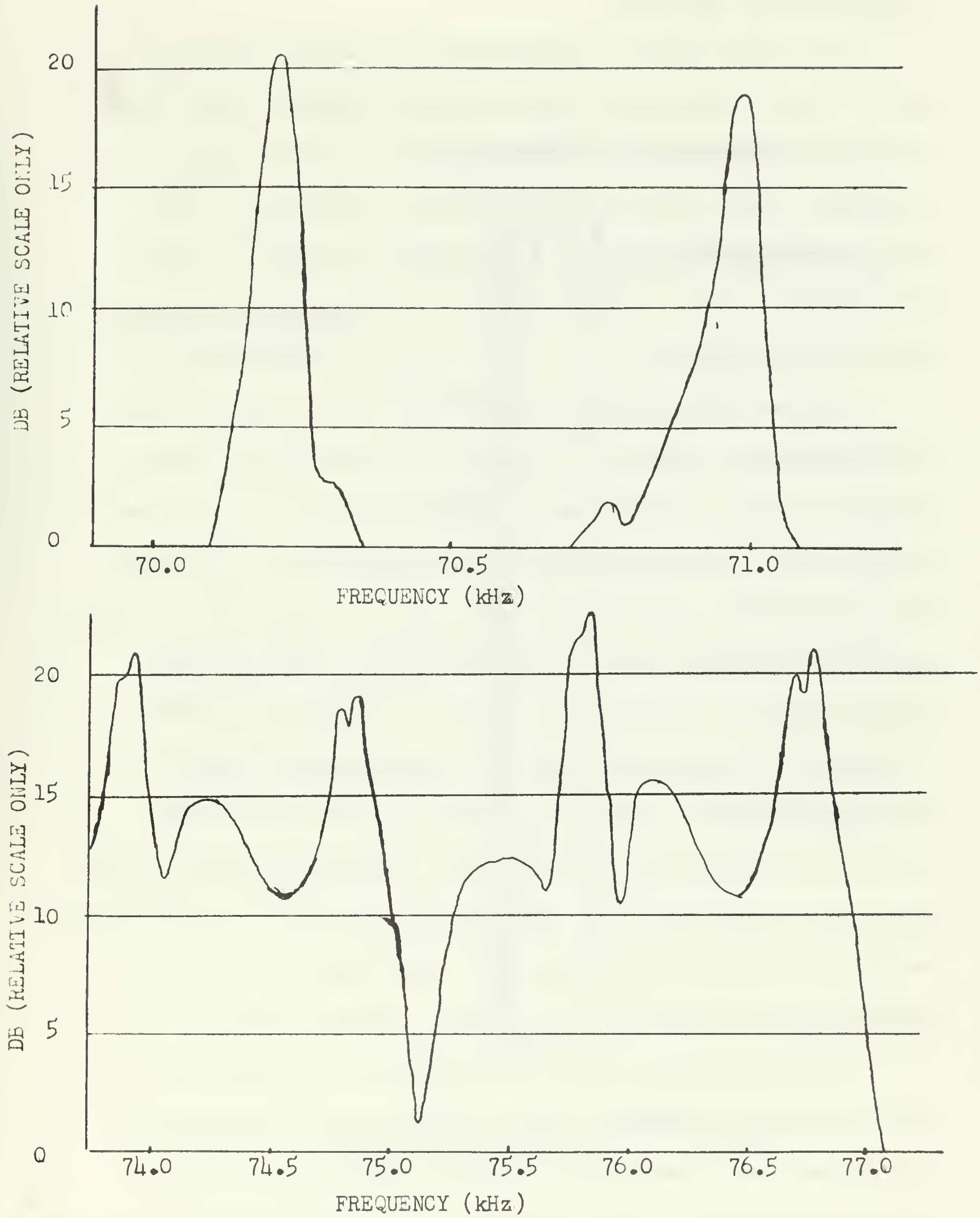



FIGURE 10 SAMPLES OF THE FREQUENCY RESPONSE SHOWING EXAMPLES OF DISTORTION

Interference Effects

To ensure that the interference effects were not due to the reflector, the frequency response was taken with the transducer suspended in the water facing the surface. The water then became the reflector. The major interference effects were still present, which proved that the reflector was not the primary source of the interference.

It was then assumed that much of the interference in the pattern was due to unwanted reflections from the air pocket at the back of the transducer. To remove this pocket, the transducer was fitted with a plexiglas back designed to minimize reflections (Figure 11). The pattern obtained using this transducer also showed many interference effects, while the minimum bandwidths increased to approximately 195 Hz at 90-100 kHz maximum Q $\approx$500). Therefore, although the air pocket contributed substantially to the energy retained by the system, it was not responsible for the major interference effects noted in the frequency response.

Dependence of the Q on the Time of Polarization

At this time, it was not possible to reproduce the frequency response curves accurately, even though the trials were made only a short time apart. It was then noticed that the bandwidths at the resonant frequencies changed with time, particularly at lower frequencies, apparently due to the length of time the polarizing

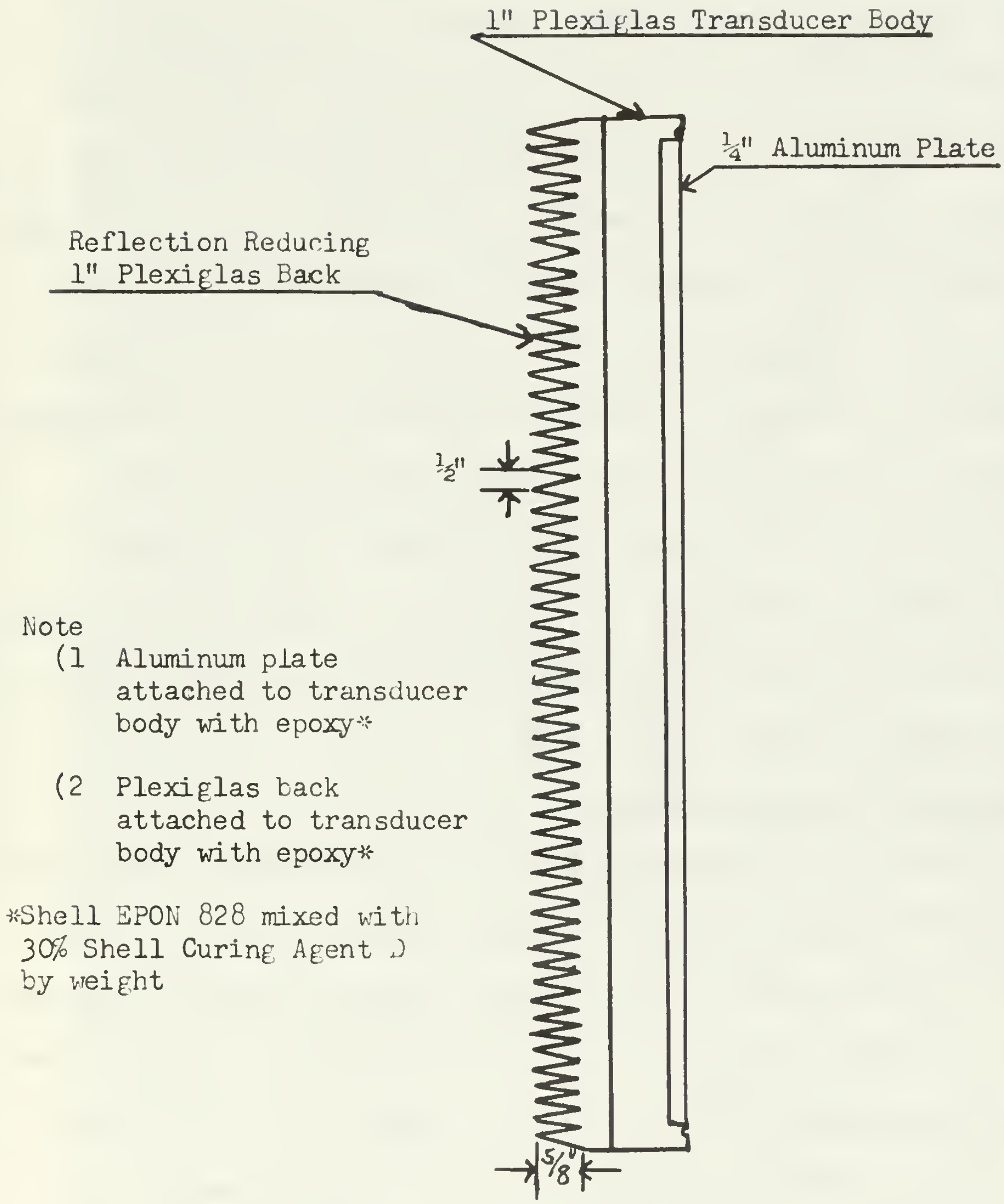



FIGURE 11 24" TRANSDUCER FITTED WITH PLEXIGLAS, REFLECTION REDUCING BACK

voltage was applied. To check this assumption, bandwidths were observed as a function of the time the polarizing voltage was applied at several frequencies below 25 kHz. Three typical results up to 5 hours polarization time are shown in Figure 12. Additional tests showed that after polarization of more than 24 hours, a condition of stability had been reached and the bandwidths were repeatable above a frequency of 20 kHz within the limits of analysis (1-2 Hz). Below 20 kHz variations of about 4 Hz still existed in the bandwidths from run to run. To ensure stability of the system with respect to the polarizing voltage, the voltage was applied at least 24 hours prior to any experimental work and was retained during the entire time that the particular transducer was used.

Variation of the Mylar Face

Since it now appeared that the interference effects were probably not caused by a single factor, but more likely were the result of several small unwanted reflections, it was decided to attempt to provide a transducer face which would not deform. It should be noted that even though the interference effects were present, it was still possible to analyze the data over most of the frequency range. Only in the range of 45-55 kHz did these effects become large enough to present serious problems to the analysis of the response curves.

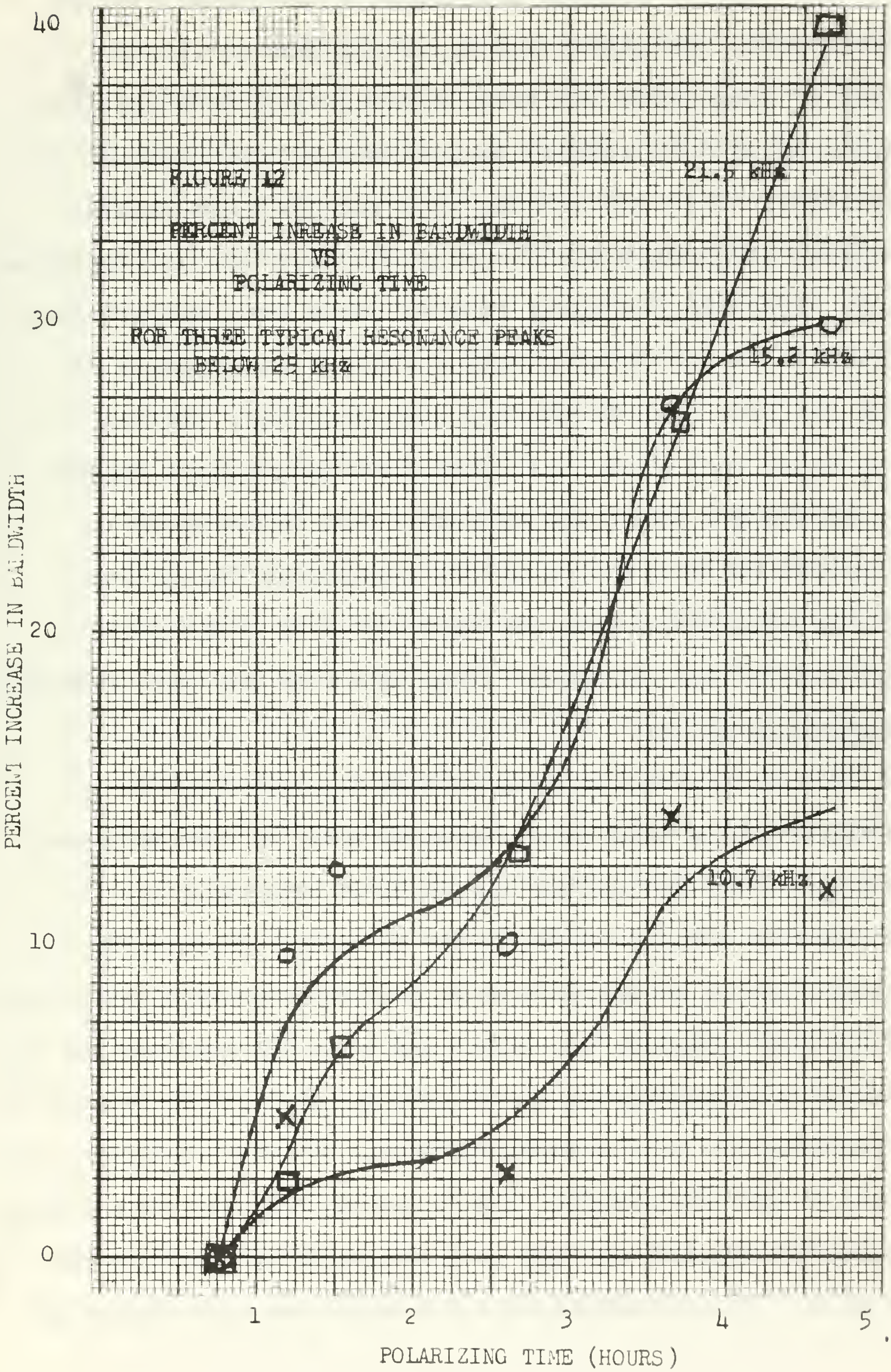


FIGURE 12
PERCENT INCREASE IN BANDWIDTH
VS
POLARIZING TIME
FOR THREE TYPICAL RESONANCE PEAKS
BELOW 25 kHz
21.5 kHz
15.2 kHz
10.7 kHz
PERCENT INCREASE IN BANDWIDTH
POLARIZING TIME (HOURS)
40
30
20
10
0
1
2
3
4
5

In order to provide a transducer face which would not stretch, the aluminized mylar was coated with a layer of Shell EPON 828 Epoxy Resin (mixed with 30% Shell Curing Agent D by weight) approximately 1/16" to 1/8" in thickness. This surface was then painted with liquid neoprene to provide additional protection to the transducer face. Although the epoxy face did lift from the aluminum plate due to the internal air pressure, it appeared to keep the face from stretching substantially. It was also noted that after the epoxy coating had been added, the system Q's increased markedly, indicating greatly increased reflectivity from the transducer face. The minimum bandwidths obtained were 25-45 Hz obtainable over most of the frequency range above 25 kHz (max $Q \approx 3500$).

Temperature Effect

Since calibration runs were to be made in the laboratory, and data to be taken at sea, it was necessary to ensure that the system showed no effects due to temperature changes on the order of those which would be experienced in going from laboratory to ocean conditions. A frequency response was taken and then the temperature was lowered by 8 degrees F. (from 60 degrees F to 52 degrees F.) by placing ice in the anechoic tank. Another frequency res response was then taken. Approximately 20 resonance peaks between 20 kHz and 100 kHz were analyzed and the two runs compared. These bandwidths differed by no more than 2 Hz

between runs, which was within the experimental accuracy limits of the apparatus. Since these differences appeared to be randomly distributed between increases and decreases in bandwidths, it was concluded that temperature changes of this magnitude would not effect the accuracy of the apparatus when used at sea. The temperature of the ocean where the system was to be tested (Monterey Bay) was about 55 degrees F. during the time of the year that this experimentation was in progress.

<u>Effect of Hydrostatic Pressure</u>

Although it appeared that the mylar transducer face was undergoing only minor stretching after the addition of the epoxy coating, it was found that the epoxy cracked and shattered due to the internal pressure differential which then caused the mylar face to stretch. The effect on the frequency response was noted when the system was tested at sea. A calibration run was made prior to the sea trials. Runs were then made at sea to depths of 40 feet. Upon completion of the runs the face was visibly stretched. When the system recalibration was made, two runs were taken, one at the usual calibration depth of two and one half feet (from the water surface to the center of the transducer) and one at a depth of six and one half feet. The second recalibration run gave bandwidth values within the experimental accuracies of the equipment when compared to the original calibration run,

however, increases in the bandwidths of about 9-13 Hz or about 30-40% were noted on all resonances of the first recalibration run. The face had apparently shifted during the handling of the rig and this served to dramatize the effect of the stretched face on the system response.

Since it appeared that the air pocket substantially affected the operation of the system, it seemed desirable to find a method of retaining the air pocket while minimizing its effect on the face of the transducer. Two methods of accomplishing this were attempted. The first was to fit the transducer with a solid wood back (Figure 13) (wood was used since it was readily available and easy to work with) which would retain the air pocket, and yet would not allow it to compress and force the face to stretch. This modification produced a very poor system response with bandwidths which were in excess of 300 Hz. The second method was to reorient the frame, lowering the transducer into the water in a face down orientation, so that the pressure gradient would hold the face to the aluminum plate. The pattern obtained was for the most part so poor that it could not be analyzed. By reorienting the frame to its original position, so that the face was again lifted from the aluminum plate, the frequency response improved and within a few minutes had returned to its original narrow bandwidth response. This indicated that the air pocket at the back of the transducer was not in itself as critical as had

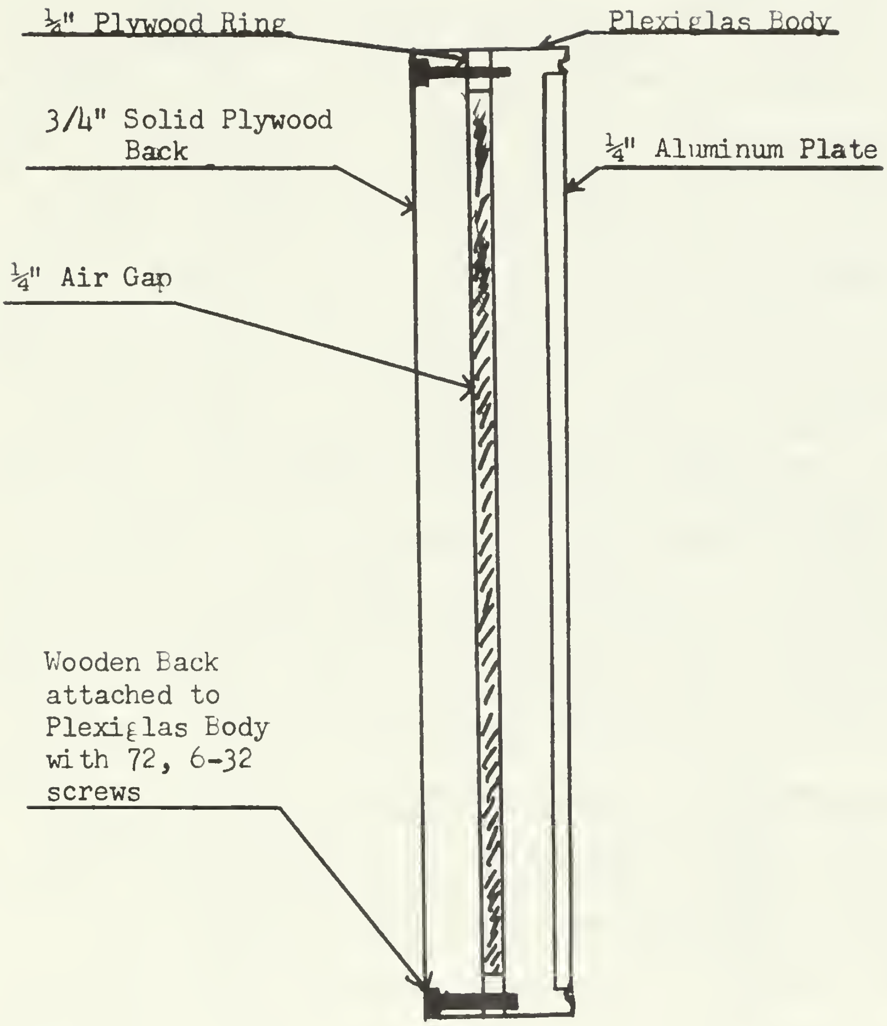



FIGURE 13 24" TRANSDUCER BODY FITTED WITH 3/4" WOODEN BACK

been previously believed. Rather it provided a source for the air pocket under the face and it was this pocket which improved the system response.

Several new attempts were now made to produce a face covering which would not permanently deform due to the interior pressure differential, but would allow formation of an air pocket under the mylar face. First a covering of approximately 1/8" of plastic (FITZ E Clear Casting Resin) was tried. This material did not adhere to the face of the transducer and was therefore unsatisfactory. Next, combinations of EPON 828 and EPON 871 were used, the EPON 871 reduces the rigidity of the EPON 828 and thereby lessens its tendency to crack and shatter. A combination of EPON 828 and EPON 871 mixed in a 1:1 ratio proved to be too flexible. A face made of this combination stretched so easily that an extremely large air pocket formed. The resulting pattern was so poor that no quantitative data could be obtained. A mixture of EPON 828 and EPON 871 in a ratio of 4:1 was then tried. The response obtained with this face was not useful for quantitative data below 30 kHz and interference effects became the dominant feature of the response above 50 kHz.

At this point the transducer-reflector system was deemed to be unsatisfactory for reliably measuring the effects of bubbles in the ocean.

## C-1 SYSTEM CONCEPT

When it became evident that the resonant system using a mylar transducer as both transducer and reflector was unsuitable for measuring bubbles in the ocean, it was decided to attempt to use external mylar transducers to excite the resonant modes of a reflector-reflector system. The first design investigated is shown in Figure 14. This system utilized four, two feet square reflectors and four rectangular (2 1/8" x 31") mylar transducers which were mounted in the corners between the reflectors so that reflections from them would be minimized. The frame used was 33" x 33" x 36" and was composed of aluminum slotted angle. To minimize reflections from the frame all internal surfaces of the frame were covered with rubberized horse hair.

The electronics used with this system were the same as used previously in the transducer-reflector system. The system response was recorded using the voltage level recorder.

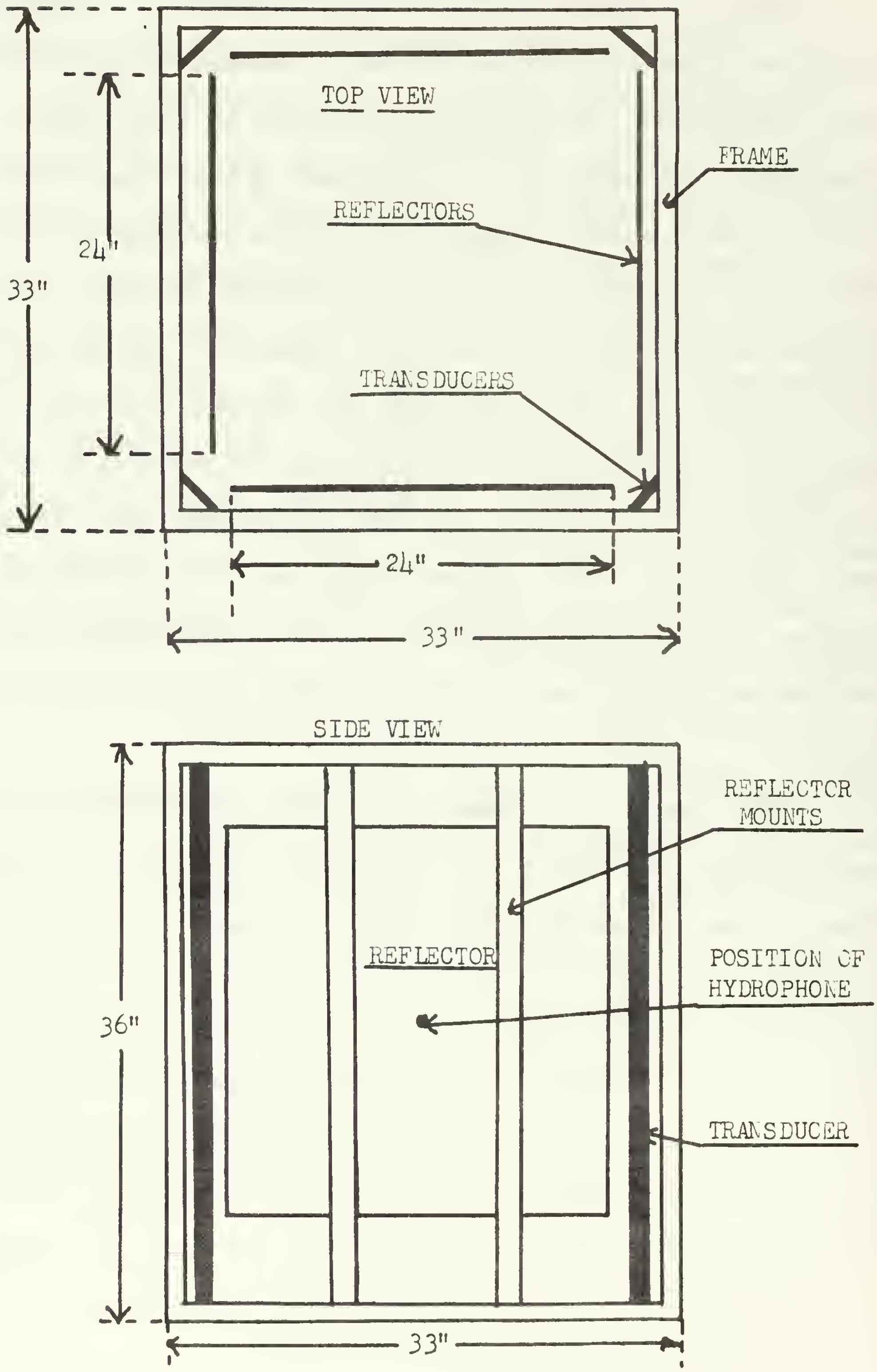



FIGURE 14 REFLECTOR-REFLECTOR SYSTEM USING EXTERNAL MYLAR TRANSDUCERS.

## C-2 RECTANGULAR MYLAR TRANSDUCER

The transducers used in this system (Figure 15) were designed to introduce as much energy into the reflector system as possible through the limited access areas between reflectors while exposing minimum reflecting area. It was at first felt that four transducers would be necessary to introduce sufficient energy into the system to cause it to resonate. It was found, however, that one transducer was sufficient to provide a signal which could be recorded and analyzed. Addition of more transducers did not improve the system response, and since the transducers did present some reflecting area, only one transducer was used. Polarizing voltage used was 300 volts d.c. and the signal voltage was 10 v. rms.

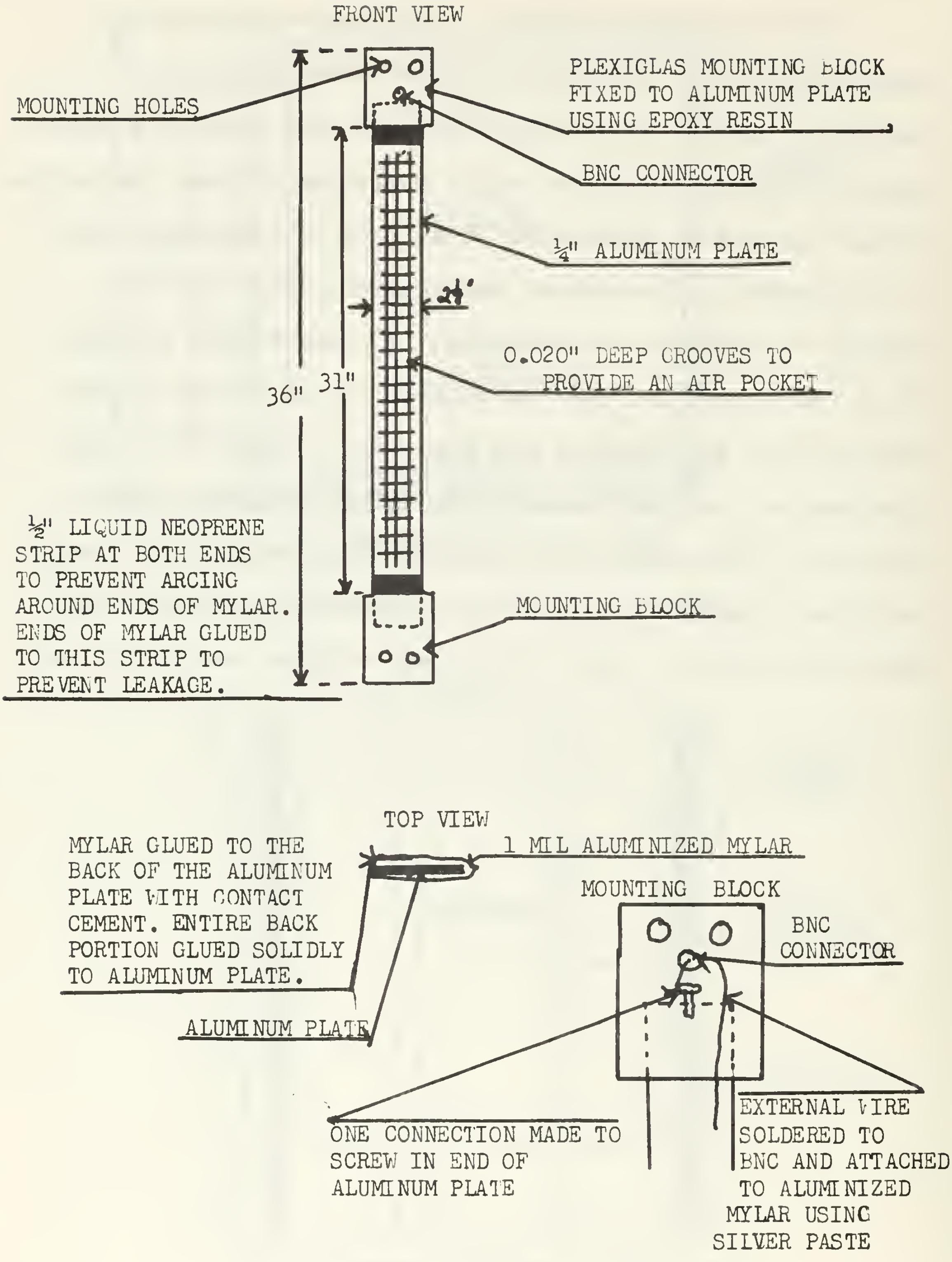



FIGURE 15 RECTANGULAR MYLAR TRANSDUCER

## C-3 REFLECTORS

The resonant system was originally built and tested using four, two feet square, 5/16" aluminum plates. This provided two reflector pairs between which standing waves could be generated. The reflector pair separations were 71.9 cm. and 76.5 cm. The response observed with this system was not only poor, but the maxima and minima did not appear to follow any regular pattern. It was believed that these irregularities were due to interference between the two standing wave patterns set up between the two reflector pairs. To reduce this interference, two of the reflectors were removed. The pattern was still not good enough to yield meaningful quantitative data, but it was now regular and repeatable over the frequency range.

To attempt to provide a better reflector, and thereby a higher Q system, the aluminum plates were covered with a $\frac{1}{4}$" layer of polyethylene foam. The system response using the combination reflectors was little better than when the plain aluminum had been used. However, several sharp peaks (bandwidths of about 20-30 Hz) were noted between 40-50 kHz. This was the only range in which such peaks were seen. Since this is the range in which the interference effects were most prominent in the transducer-reflector system, it was concluded that these peaks were interference effects due to the double character of the reflectors. Throughout the rest of the range the response was too poor to analyze.

A third type of reflector was also tried. This pair of reflectors was composed of the aluminum plates, with 1" paper honeycomb glued to them, and the honeycomb was covered with $\frac{1}{2}$ mil mylar. These reflectors were made to approximate 1" air gaps. To prevent standing waves from forming in the 1" air space, small amounts of fiber-glas were placed in the honeycomb to act as a damping agent. These reflectors provided a system response which was no better than that obtained with the aluminum or combination reflectors.

## D-1 GENERAL CONCLUSIONS

The great advantage of the mylar transducer for use in a resonance system in water is its broad frequency response. This permits resonance peaks of a standing wave system to be independent of the source resonance. However, it was found that the tendency of the mylar transducer face to stretch produced variable reflections and it was therefore not possible to obtain reliable data. The standing wave system using a mylar transducer as both source and reflector is therefore unsatisfactory for measuring bubble concentrations in the ocean.

The following things were determined regarding the transducer-reflector system during the experimentation and evaluation process:

1) The best system responses obtained were system bandwidths on the order of 25-45 Hz (maximum $Q \approx 3500$) using an EPON 828 epoxy transducer face covering of about 1/16" to 1/8" in thickness. (Maximum Q of Buxcey, McNeil, and Marks[2] $\approx$ 2500 at 100 kHz).
2) Interference effects in the resonance pattern of the system investigated were the result of several unwanted reflections (from the interfaces and air pockets within the transducer and from the aluminum-polyethylene foam reflector) and could not be attributed to a single source.

3) Using a voltage level recorder, successive trials could be made with an accuracy of 2 Hz in the bandwidths from run to run above 20 kHz provided the face did not change during the time between runs.

4) The system is not adversely affected by temperature changes on the order of 8 degrees F.

5) For a plate-transducer separation of approximately 75 cm., maximum sweep speed to obtain a fully developed pattern was found to be about 100 Hz.

6) To obtain stability between runs, the transducer must be polarized at least 24 hours before use.

Preliminary investigations into an externally excited reflector-reflector system indicated:

1) Using two reflector pairs with unequal spacing introduces interference effects into the system response.

2) Using a two reflector system excited by one rectangular mylar transducer produced a very low Q system which did not yield any quantitative data.

3) Of the three pairs of reflectors used (aluminum, aluminum-polyethylene foam, and

paper honeycomb) only the aluminum-polyethylene reflectors gave any high Q peaks. These peaks appeared only in the 40-50 kHz range and were attributed to the dual character of the reflectors.

Since weight considerations were of great importance in the construction of the systems investigated, the reflector materials which gave the best system response were pressure release surfaces. In all cases the hydrophone was inserted through the reflector into the pressure field. With the hydrophone mounted in this manner there will be an averaging effect of the pressure field over the length of the hydrophone. Since the reflector is a pressure release surface, this method of mounting the hydrophone, although easy to accomplish, will not provide the best response. If further work is done in this area, a new method of mounting the hydrophone (parallel to the reflector) should be used to minimize the averaging effect.

Since the system response of the reflector-reflector system showed very low Q's using two reflectors, and the use of two reflector pairs at unequal separations caused many interference effects, it is recommended that four (or possibly six) reflectors with equal reflector pair spacings be used to increase the system Q's.

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13. ABSTRACT

That bubbles affect sound propagation in the ocean has long been known. However, quantitative data on the concentrations and distribution of bubbles near the surface of the ocean is not available. A one-dimensional, high Q, standing wave system was constructed and evaluated to determine bubble concentrations by measuring the effect of bubbles on the system Q's. It was tested to depths of 40 feet and in the frequency range of 10-100 kHz. This system used a mylar electrostatic transducer as the sound source and also as one of the reflectors. System Q's of 3500 were obtained. It was possible to measure attenuation to $\pm 0.019$ db/m above 20 kHz. Hydrostatic pressure caused variations in the face of the transducer thereby making the system unstable. The mylar transducer is therefore unsuitable for use as both source and reflector. Initial investigations made into using the mylar transducer to externally excite a reflector-reflector system are also described.

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